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A STUDY OF COST IMPLICATIONS FROM NOT MAINTAINING A PRODUCT CONFIGURATION SYSTEM

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Abstract: *This article is a case study investigating the cost implications of using a Product Configuration System (PCS) that was not sufficiently maintained. It presents a case study that demonstrates and quantify the potential financial loss of relying on a PCS to generate quotations without sufficient focus on updating and correcting the cost data and product offerings. The study finds that comparing quotations made from a not-maintained PCS, with recalculations of the same projects in a newer updated PCS that the company in a period of one year in average miscalculated the costs too be 20% lower than the real costs. We concluded that the cost of not maintaining a PCS can be far higher than the costs to update and maintain the system and furthermore that the success of PCS reported in the literature might not be consistent for long time of use of PCS if the systems are not properly maintained.*

Key Words: ***Product configuration system, Cost calculation accuracy, benefits of product configuration systems, challenges of product configuration systems, case study***

1. INTRODUCTION

PCSs are information systems that support the specifications of the product configuration as well as creation and management of configuration knowledge [1]. Several benefits of PCSs have been reported such as shorter lead-time for generating specifications [2,3], improved accuracy of product specifications [1,3], improved control of product assortment and less repetitive work tasks [4,5]. In order to harvest the benefits from a PCS significant work must be undertaken including significant cost, time and possible restructuring of product assortment and work processes [6]. Several approaches to develop a PCS exist that all mention the importance of maintenance [7–10]. However not much has been reported on the consequences of a reduced maintenance effort. This research work is using a case study to investigate the financial consequences of not maintaining a PCS properly. In order to investigate these effects the following research question is developed:

RQ. *What are the cost implications from not maintaining PCS?*

To test the research question, a case study was performed in a case company that had experienced changes in market offerings and manufacturing costs without paying sufficient attention to updating the PCS. After the realization that the product offerings created by the PCS were off the company developed an updated PCS and re-calculated all contracted projects to investigate the cost difference. This discrepancy between the old and the new PCS provided an opportunity to study 81 projects consisting of 2655 sold products and the impact on the cost estimates. The results indicate that the cost of not maintaining a product configuration system can potentially be more costly than spending the resources to make sure the system is up to date at all times.

2. LITERTURE REVIEW

Literature on product configuration systems (PCSs) discusses in detail the realized benefits from their implementation [4,11,12]. More recent research focuses on the challenges of implementing PCSs [13–15]. However the cost of not maintaining a PCS is barely discussed. Therefore, the related literature review touches upon the cost of maintenance of IT software in general, the benefits from updating the IT systems and the challenges regarding the maintenance tasks.

PCS are a proven concept, adding significant value for companies of configurable complex products. Even though the decision to implement a PCS comes with the expected cost of software, training etc. studies have shown that the return on investment (ROI) on such a project is very high [16]. The success of information systems and technology leads to better organizational performance and reduction of the overall costs [17].

Therefore the implementation of a PCS is a strategic decision towards achieving several benefits. To be able to reach that goal, companies have not only to set up the configurator and use it, but also ensure that it is updated. The maintenance of the data in the configuration system is of great importance, in order to lead to accurate products and price calculations. The maintenance of the IT systems is connected to the overall maintenance strategy of the management systems in a company [18]. However, this phase is considered as less important than the initial development and implementation of the software [19].

The phases of software development include requirements identification, design, implementation, test, operation and maintenance [20]. For a PCS the maintenance part includes updating and maintaining the product features included in the system, along with their level of detail [21]. The main challenges identified in the literature in respect to the maintenance phase of the PCS are related to the product complexity, the frequency of the changes in the product, and the accessibility and knowledge sharing of the related information to perform the maintenance tasks [13].

Complexity is one of the main difficulties both in development and maintenance of software [22]. In terms of PCSs, the complexity of handling of configuration data increases along with the complexity of products, and then the task of maintaining the PCS becomes rather challenging and time-consuming [23,24]. The failure of communicating the knowledge during the maintenance phase of the PCS is considered of significant importance among manufacturing companies [13].

Ref. [19] conducted a survey to analyze how the task of maintenance and enhancement of software is perceived by companies. The results indicate that the demand in terms of resources is high and the execution of the task is the most important management area. Maintenance tasks of implemented software are categorized into three groups; perfective, adaptive and corrective maintenance [25]. Even though the allocation of the specific task under these groups is subjective to the view of the user, the consequences of not performing the tasks remain the same [18]. Maintenance typically comprises of 60 percent on average of the cost during a software system's life cycle [26]. However, the most important cost regarding maintenance is related to the consequences of not updating the PCS [7,27–29]. Poor data quality has a negative impact on the economic performance of an organization (Ballou et al., 2004; Wang & Strong, 1996) and its efficiency, whereas high quality data are of great importance towards its success [30–33].

The cost of corrective action [34] occurs when the expectations of the customers in terms of quality and time are not possible to be satisfied by the manufacturing company. Therefore, more resources are allocated to ensure that the delivered product satisfies the agreed upon requirements. It terms of PCS, this refers to validation of the configuration data, which consequently affect the quality of the product specifications, lead time and estimated prices [23,35].

The economics-driven evaluation on data management decisions in regards to the maintenance of data repositories is examined in terms of costs and benefits [36]. The results of the analysis indicate that even though the cost of maintaining the system can be relatively high, the economic and business benefits can justify the need. In terms of PCSs, this could be argued by taking into account the studies on ROI for such an investment [16]. The cost of maintenance of a PCS is included in the ROI calculation and still the savings are significant (eg. 20m euro over a 5-year period) [16]. The need for continuous update of the PCS is imperative, to ensure validity and accuracy of the configuration data. This leads to fewer errors in the system and consequently to the end product, but also prevents failure of the system and enhances its general acceptance [25]. Thus, the benefits of the use of PCSs are not evaluated only in terms of usefulness, but also in terms of their impact to the overall performance of the company and the total cost [17].

This need for update of the configuration data is mainly driven by the changes in the requirements of configurable products, which often occur due to external factors, such as customers, suppliers, and legislation [24]. Moreover, if the changes require a new logic or new features to be added to the software system then they have to be specified and incorporated [37]. These changes need to be communicated and updated in the PCS and other data management systems, to ensure the validity and accuracy of the configuration outcome. This can be connected to the need of having a documentation system to cover not only the development phase, but also the maintenance [38].

The benefits of maintenance support from the vendor's perspective are discussed in the literature of enterprise resource planning (ERP) systems. These benefits include operational cost reduction, in terms of time and cost due to re-entry errors, data entry and general errors in delivery [39]. The maintenance activities in the ERP systems include correcting logic errors and revision or enhancement of the system to satisfy user requirements [40]. Unsuccessful ERP maintenance would result in the system not achieving its whole potential benefits [41]. In general, the cost of maintenance is discussed in detail in the literature [40,41], but the cost implications of not maintaining the system are not discussed.

Tracking and tracing all changes of product models in product lifecycle management (PLM) and CAD systems is a main part of the configuration management tasks [42]. In a similar way, the need for managing product data, process and project data is highly relevant for documentation management, especially over time and for products with long life cycles [42].

Erroneous master data, including product data, prices, suppliers data, can lead to significant costs [23]. Even though the importance of data quality, in terms of having up-to-date and valid data, is discussed in the literature [43], there has not been established a link between poor data quality and monetary loss [23,44,45]. Ref. [45] propose a "data quality cot taxonomy" that categorizes the potential costs due to poor data quality. However, there is limited research on the size of these cost implications [23]. In conclusion, indirect relations can be drawn based on the research work discussed in this section, pointing to the need to further examine the monetary consequences of not performing the maintenance tasks. In particular, the cost of not updating the data in the PCS has not been discussed or quantified. Hence, this work aims to contribute to this research gap.

3. RESEARCH METHOD

The purpose of this research is to identify and evaluate the cost of not maintaining the product data in a PCS. Therefore, the selected research method is case study. Case research studies the phenomenon in its natural settings, providing answers to “Why, what, and how” questions [46]. In this particular work, which has not been investigated in depth as discussed in the literature review section, case research is highly suitable as it supports exploratory research with still unknown variables and not fully understood phenomena [47].

The selected case study is considered as a highly representative example from the manufacturing industry, as the company designs, manufactures and installs their complex configurable products. They support the sales process via a PCS. The company has been using the PCS for 7 years, therefore it is considered mature enough to be examined in this study, providing a depth of observation [47]. The main limitation of the single case study is related to the generalizability of the findings [47].

Data collection includes quantitative data on cost categories (salaries, materials, prices, outsourced components etc.) from the company’s configuration system, observations and semi-structured interviews with the head of sales. Semi-structures interview are selected to ensure that the relevant aspects of this research are addressed by the interviews, but also to provide the freedom to discuss emerging aspects mentioned from the experts. These different sources of data collection allow for triangulation and validation of the collected data [48,49]. The unit of analysis is on a project level. The sample of this case study includes 81 projects sold over a year (2014). The research team had access to the company’s resources for data collection for a period of 6 months. The following section describes the details of the case study and collected data.

4. RESULTS

4.1. Background of the case company

The case company was a Scandinavian company that provided system deliveries in the manufacturing industry. In 2013 the turnover was 34 mio. € and the company employed 130 people. The offering of the company was product installations and handling of legal requirements for the customers. The projects consisted of standard solutions based on a standardized product assortment from five different product families and the time from contract to finished project would usually be between half a year and 2 years. Every project would delivery would be several different products for different customers which would all share some costs of initial setup of machinery. A signed contract was fixed in price and would not vary if the company had to make changes to the products which stresses the need of correct calculations. The cost-estimations provided by the PCS had historically proven to be accurate with only minor deviations. The company had four major expense categories which was materials, salary for workers performing the installations, sub-suppliers and shared costs. The distribution of costs in the individual project costs were in 2017 approximately salary (13%), materials (55%), sub-suppliers (24%) and shared costs (7%). The company had since 2009 used a PCS to generate quotations on projects.

The PCS was handled by key employees from sales, development, supplier representatives and from marketing in order to make sure the offerings was correctly priced and provided sufficient offerings to cover the market. In 2013 a key employee left for another company and the efforts to maintain the product assortment and corresponding PCS was no longer of primary concern to the company. Meanwhile 2 years passed without significant changes from suppliers or the market resulting in a successful business without much need for adjustments. At some point competition and market requirement increased which changed the product offerings drastically – but since the company no longer had much focus on the PCS – the offerings from sales continued to be the same prices as in 2013 with no changes even though salaries were re-negotiated, materials were calculated based on different principles and stricter regulations required resulting in increased costs. In 2015 the company realized a loss on most projects compared to the calculation and increased the costs of all products by a fixed percentage in hope that it would cover some of the costs that was not included in the old PCS. At the same time an initiative was taken to update the PCS to fit the new structure which was completed in the beginning of 2016. In order to understand the difference between the sold projects configured in the PCS from 2013 and the actual prices all projects were re-calculated in the new PCS developed in 2016. The timeline of the initiatives taken between the old PCS (2013) and the new PCS (2016) can be seen in figure 1.

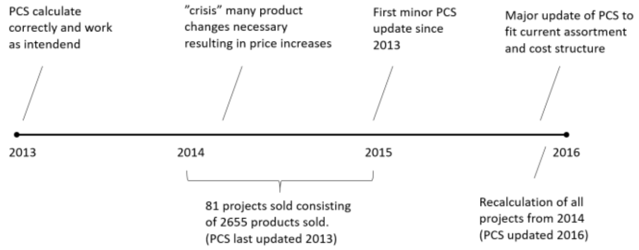

Fig. 1. *Timeline of initiatives taken to update PCS in the case company*

4.2. Configuration of project costs

The PCS structure used by the company was roughly the same in the PCS from 2013 and the PCS from 2016 which can be seen in a schematic representation in figure 2. The PCS takes user inputs in the form of product design and work process specifications. The user inputs would then be translated by an inference engine to process the knowledge into a feasible product solution, a quotation letter and a document with cost summaries of the specific solution. For internal use the company generated a time-estimate based on the expected salary and time it would take to finalize the project in order to calculate the shared costs. The cost estimate was divided in four major cost categories: salary, material, subcontractor and shared costs. In this article the deviation between the calculations made in 2014 after a drastically changed market by the PCS designed in 2013 is compared to the same cases recalculated in the new PCS implemented in the beginning 2016 reflecting the actual cost structure. The cost summary helped the company to evaluate cost accuracy, identify billing mistakes, and improve quotations. The cost summary is the basis of the comparison between the projects configured in the 2013 PCS and the new 2016 PCS.

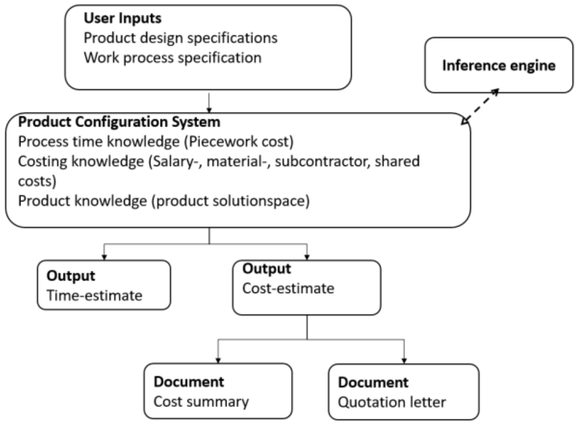

Fig. 2. *Product Configuration System setup*

4.3. Analysis of cost-estimate in a not-maintained PCS and updated PCS

The company sold 81 projects in 2014 which consisted of a total of 2655 individual product solutions based on the calculation principles from the 2013 PCS. The deviations were both calculated on a complete project basis and for the cost elements individually. The cost difference was calculated as defined in (1) and the relative deviation as defined in (2).

$$CostDifference = NewPCS\_calc - OldPCS\_calc \quad (1)$$

$$DEV = \frac{Cost\_Difference}{OldPCS\_calc} \quad (2)$$

If the re-calculation in the new PCS is higher than the old calculation the cost difference will be a positive number corresponding to a loss compared to the actual cost price. If the re-calculation is lower than the old calculation the result will be negative and indicate that the company would be able to deliver at a cost lower than what was sold. All numbers are calculated raw costs and does not state anything about how profitable the projects actually turned out. The total project sum of the period was contracted for 21.6 mio. € basd on the old PCS, the recalculated sum was 25.8 mio. € in the new PCS resulting in a miscalculation of 4.2 mio. € which corresponds to a total miscalculation of 20% (table 1). The individual contributors to the total cost deviation was investigated further through analysis of individual cost elements (figure 2). According to the case company the reason for 21% increase in salary was mainly due to increased salaries for the installation work. The 14% increase in material costs was explained by increased raw material costs and a tendency to sell products too simplistic compared to the reality of the product design. The 43% increase in supplier cost was explained by a single contributor that was very low compared to the actual cost that had not been identified by the company. Additionally some projects needed to be changed from the standard solution which had been sold to a more expensive solution that was not possible to configure and price in the PCS from 2013. The shared cost would be derived from the other costs, namely salary-, material- and supplier costs. As the before mentioned costs increased, the shared costs increased as well due to the interconnectedness. A visual comparison of the total cost calculation for all projects can be seen in figure 2.

Table 1. *Deviation in sum of total project costs from 2014 in 1000 €*

	Salary cost	Material cost	Supplier cost	Shared costs	Total costs
New calculation	6.597	13.766	1.658	3.857	25.879
Old calculation	5.458	12.087	1.156	2.907	21.609
Difference	1.138	1.679	502	950	4.270
Increased cost in percent	21%	14%	43%	33%	20%

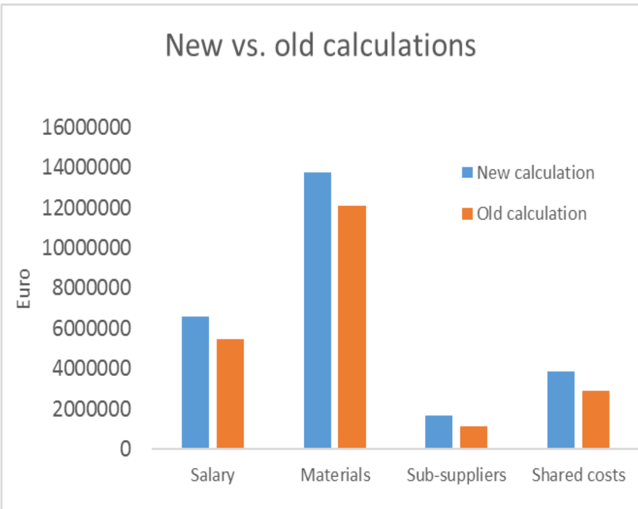

Fig. 2. *Calculation from new PCS compared to old PCS in €.*

4.3.1. Comparison of individual cost element accuracy

All of the projects were plotted for each cost category in a column diagram and sorted from largest deviation to the smallest deviation in order to investigate the distribution of the projects. This was done both for the absolute difference between old and new calculation measured in euro and in relative deviation compared to the cost of the project. It was observed across all projects that the larger the project, the greater the absolute deviation was. The relative deviation would mostly be impacted by the execution of the project and its individual products and in particular whether the project sold would need major changes compared to the solution that was initially sold.

4.3.2. Comparison of total cost on a project basis

The total cost difference in all projects occurred due to a general raise in prices and changes in product structure that was not reflected in the old PCS. The numerical cost difference is dependent on the size of the project, i.e. bigger projects tend to have a larger absolute deviation and smaller projects seem to have smaller absolute deviations. The relative deviations are not as dependent on project size. A few projects are sold with a deviation above 40% which according to the case company happened due to drastic project changes due to unforeseen circumstances. Therefore, some of the worst cases might not be directly attributed to the PCS since the costs could not have been known the first time the requirements changed. However most of the following deviations can be directly related to the information stored in the PCS since the increased costs could have been known at that point in time. The projects with the biggest absolute cost difference is the same projects in all categories whereby the most deviating projects measured on relative deviation vary more when looking into the different cost elements.

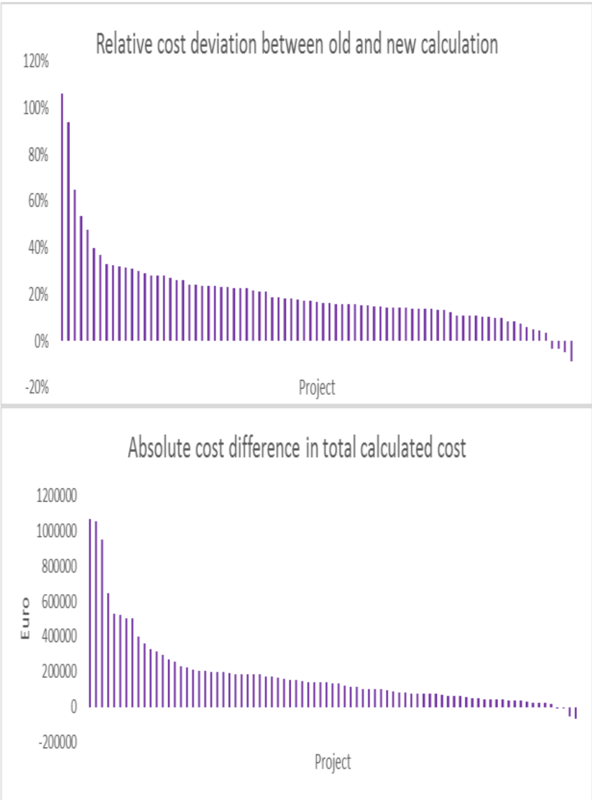

Fig. 3. *Absolute and relative cost deviation of 81 different projects from 2014*

4.3.3. Salary cost

According to the case company the difference in salary cost was mainly related to increases in salary which was adjusted based on annual negotiations. The salary had not changed much for a long time so the workers managed to get markedly better salaries. However, the old PCS was not updated accordingly and did not reflect the salary changes which can be seen in figure 4. The average increase in salaries was 21% but the raise was also dependent on a case to case basis were some processes turned out more complicated than expected resulting in a need to spend more time performing the installations.

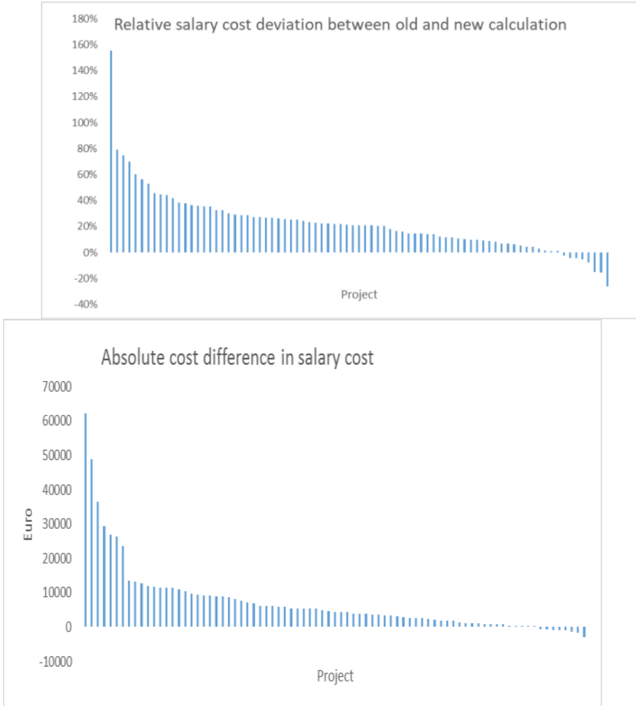

Fig. 4. *Absolute and relative salary cost deviation of 81 different projects from 2014*

4.3.4. Material cost

The differences experienced between the old and the new PCS in material cost was related to changes in product design and raw material prices. The products often needed to be designed a bit more complicated than initially expected resulting in more material use. A few projects deviate largely due to unforeseen circumstances that might not have been possible to implement in the PCS from the first occurrence of such problems. However, after a while the costs were settled and most of the projects in the deviation range between 5% and 25% could have been reduced or greatly mitigated by an updated PCS implemented as soon as the company got experience with the specific challenges and added possible principles and designs to choose in the PCS.

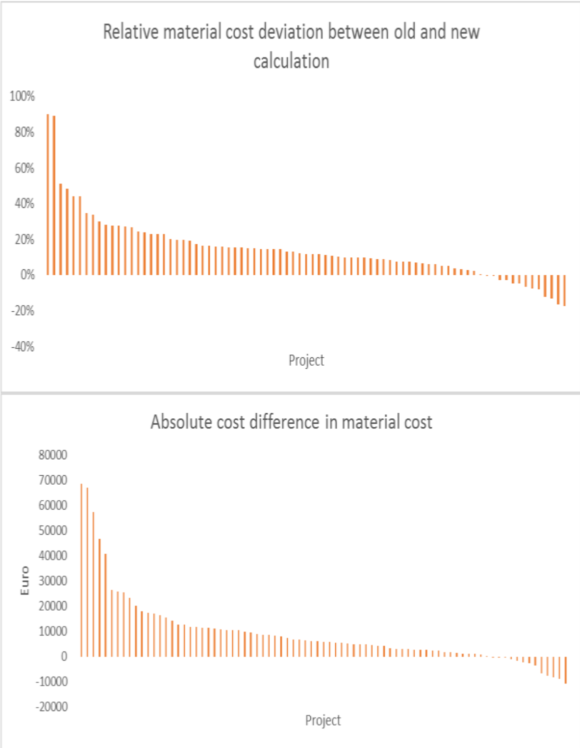

Fig. 4. *Absolute and relative material cost deviation of 81 different projects from 2014*

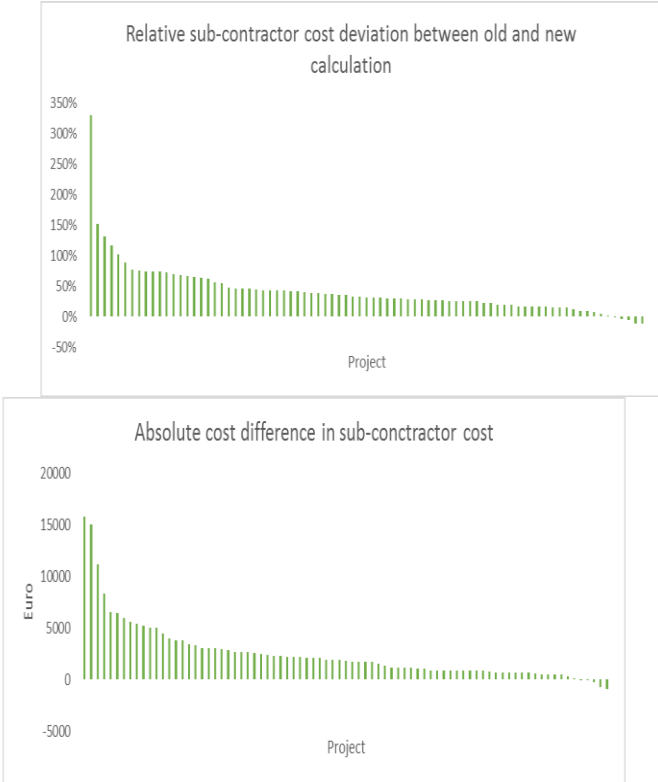

Fig. 5. *Absolute and relative sub-contractor cost deviation of 81 different projects from 2014*

4.3.5. Subcontractor costs

The cost element experienced the biggest cost increase of 43% was the subcontractor costs. The explanation for that increase was, just like the other cost elements, for the most drastic cases with deviations above 100% not necessarily preventable. But the forthcoming projects would be possible to implement with a new cost structure reflecting the cost increase of almost 50% on most cases for the sub-contractors. The role of the sub-contractor was partly to deliver external approvals of calculations and constructions principles which in some cases resulted in redesign of the product and therefore increased costs in other categories. Additionally, a single large expense was not correctly registered in the old PCS and often overlooked by the salespeople resulting in additional discrepancy between sold price in the old PCS and the new PCS.

4.3.6. Shared costs

The deviation in shared costs was directly influenced from the other cost increases. The biggest contribution to the shared costs was miscalculation of the process time to perform the installation which in turn resulted in increased salaries and extended need to rent and allocate machinery for installations. Another contributing factor was that some installations was sold too simplistic which would further increase the time needed to perform the installation.

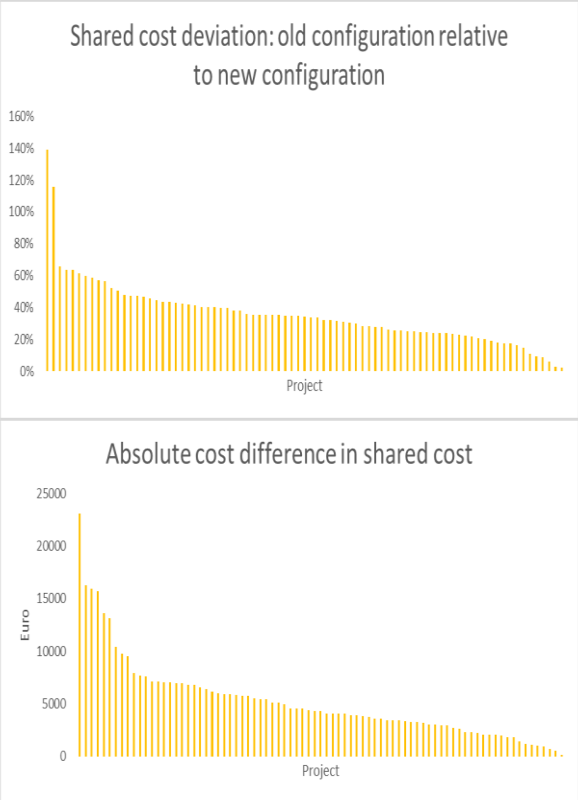

Fig. 6. *Absolute and relative shared cost deviation of 81 different projects from 2014*

4.4. Reasons for deviations according to case company

In order to understand the deviations and miscalculations in the different projects and cost elements semi-structured interviews were conducted with the head of sales. He explained that the company had experienced many rapid changes in requirements based on increased competition, focus on their particular market and impact on the society at large. The increased focus hindered project executions for a period of time which required fast changes in product and process. For good reason the focus of the company was to fix the immediate situation and unfortunately the company did not pay enough attention to the projects being sold at that time of crisis. The management knew that the projects would not turn out as good as earlier, but did not expect such a big increase in costs. In an semi-structured interview the head of sales explained many specific problems related to the different miscalculations between the new and old PCS and specificities of products that were not taken into account during sales and how some prices were raised in another part of the company without implementing equivalent changes in the PCS. Initiatives were taken to improve the PCS but the project was taking much longer than anticipated. It was also mentioned that the company might not have been good enough to follow up on all projects since the company was so used to hitting very close on the target due to the use of a successful PCS. The customers would in general not be very price sensitive because of a strong brand and being a trusted partner in that particular market, but what the customers did not understand was the sudden correction of prices in 2016 and some customers where lost questioning why a project they were ready to sign would suddenly increase noticeably in price. It was difficult for the company to guess what would have happened to the turn over if the prices had been updated in time, but they most likely would not regret having fewer projects with a better margin.

5. DISCUSSION

In this case study we have presented the potential consequences of not updating a PCS in time. The case study presented a year worth of projects calculated in a PCS that was not sufficiently maintained and recalculations in a new PCS reflecting a more correct calculation of the costs. The total miscalculation in a one year period were 4.2 mio. € corresponding to 20% increase in total cost price resulting in a markedly worse contribution for each project. The individual cost elements were investigated and it was seen that the cost elements varies for different reasons. Both external reasons that could not be entirely mitigated and some internal reasons due to lack of maintenance that could have been mitigated. It is observed in this case study that the benefits of PCS reported by the literature is not without risk. If the company rely too much on a PCS and neglect to update it in a time of crisis the implications can be detrimental to a company. The potential money lost by not having enough focus on the PCS in this case study should easily be able to finance a dedicated employee to make sure that the PCS is updated to reflect the most current prices at all times. Additionally one take away of the case is that short-term success of PCS is no guarantee of long term success if not sufficient attention is given to the maintenance of the PCS. The presented case study is based on a single case study which clearly limits the generalizability. However, due to the tight connection between the critical early decision of product design and fixed price towards the customer it is believed that this case material can explain a mechanism that stresses why maintenance efforts of sales configurators are of extreme importance.

6. CONCLUSION

The purpose of this case study was to investigate the implications of not maintaining a product configuration system. It was concluded that a lack of focus on PCS maintenance can result in great losses if not taken care of in time. In this case study the cost miscalculation for one year of sales was calculated to 4.2 mio. € corresponding to 20% of estimated costs for all projects that year. It was explained that the reason for the miscalculation was both due to external circumstances of the market environment and due to not enough focus on updating the PCS in a time of crisis which implied many changes to prices and product assortment. In this particular case the company could have saved a significant amount of money by updating the PCS a bit earlier than they did. This research is the first step in quantifying the cost of not maintaining a PCS. To improve this research more years should be analysed in order to investigate trends and get a deeper understanding of the consequences of not maintaining a PCS. The cost of not maintaining seems to have significant impact on a company's performance.

Therefore, more research are needed in order to confirm the generalizability of the phenomenon. Another topic to investigate would be to investigate the trade-off between the cost of maintenance and cost of not maintaining PCSs.

7. REFERENCES

[1] V.E. Barker, D.E. O'Connor, J. Bachant, E. Soloway, Expert systems for configuration at Digital: XCON and beyond, Communications of the ACM. 32 (1989) 298–318.

[2] A. Haug, L. Hvam, N.H. Mortensen, The impact of product configurators on lead times in engineering-oriented companies, Artificial Intelligence for Engineering Design, Analysis and Manufacturing 25 (2011) 197–206.

[3] C. Forza, F. Salvador, Managing for variety in the order acquisition and fulfilment process: The contribution of product configuration systems, International Journal of Production Economics 76 (2002) 87–98.

[4] L. Hvam, A. Haug, N.H. Mortensen, C. Thuesen, Observed benefits from product configuration systems, International Journal of Industrial Engineering: Theory, Application and Practice 20 (2013) 329–338.

[5] M. Heiskala, K.-S. Paloheimo, J. Tiihonen, Mass Customisation of Services: Benefits and Challenges of Configurable Services, Frontiers of E-Business Research. (2005) 206–221.

[6] M. Heiskala, Mass Customization with Configurable Products and Configurators, in: Mass Customization for Personalized Communication Environments: Integrating Human Factors., IGI Global, 2007: pp. 1–32.

[7] L. Hvam, J. Riis, N.H. Mortensen, Product customization, Springer, Berlin Heidelberg, 2008.

[8] C. Forza, F. Salvador, Product information management for mass customization, Palgrave Macmillan, New York, 2007.

[9] A. Felfernig, G.E. Friedrich, D. Jannach, UML as domain specific language for the construction of knowledge-based configuration systems, International Journal of Software Engineering and Knowledge Engineering 10 (2000) 449–469.

[10] J. Tiihonen, T. Lehtonen, T. Soininen, A. Pulkkinen, R. Sulonen, A. Riitahuhta, MODELING CONFIGURABLE PRODUCT FAMILIES, in: 4th WDK Work. Prod. Struct., Delft University of Technology, Delft, The Netherlands, 1998: pp. 1–22.

[11] A. Myrodia, K. Kristjansdottir, L. Hvam, Impact of product configuration systems on product profitability and costing accuracy, Computers in Industry 88 (2017).

[12] A. Felfernig, C. Bagley, J. Tiihonen, L. Wortley, L. Hotz, Benefits of Configuration Systems, Knowledge-based Configuration: From Research to Business Cases. (2014) 29–33.

[13] K. Kristjansdottir, S. Shafiee, L. Hvam, C. Forza, N.H. Mortensen, The main challenges for manufacturing companies in implementing and utilizing configurators, Computers in Industry (2018) 196–211.

[14] M. Heiskala, J. Tihonen, K. Paloheimo, T. Soininen, Mass customization with configurable products and configurators: a review of benefits and challenges, in: Mass Customization Information Systems in Business., 1st ed., 2007: pp. 1–32.

[15] L.L. Zhang, P.T. Helo, An empirical study on product configurators' application: Implications, challenges and opportunities, in: CEUR Workshop Proc., 2015: pp. 5–10.

[16] K. Kristjansdottir, S. Shafiee, L. Hvam, M. Bonev, A. Myrodia, Return on investment from the use of product configuration systems – A case study, Computers in Industry. 100 (2018) 57–69.

[17] T.A. Byrd, E.H. Thrasher, T. Lang, N.W. Davidson, A process-oriented perspective of IS success: Examining the impact of IS on operational cost, Omega-international Journal of Management Science. 34 (2006) 448–460..

[18] M. Kans, IT practices within maintenance from a systems perspective Study of IT utilisation within firms in Sweden, Journal of manufacturing technology management Iss. 24 (2013) 768–791.

[19] B.P. Lientz, E.B. Swanson, G.E. Tompkins, Characteristics of application software maintenance, Commun. ACM . 21 (1978) 466–471.

[20] G. Kumar, P.K. Bhatia, Comparative Analysis of Software Engineering Models from Traditional to Modern Methodologies, in: 2014 Fourth International Conference on Advanced Computing and Communication Technologies., IEEE, 2014: pp. 189–196.

[21] S. Shafiee, L. Hvam, M. Bonev, Scoping a Product Configuration Project for Engineer-to-Order Companies, International Journal of Indusstrial Engineering and Management 55 (2014) 207–220.

[22] J. Prochazka, Agile Agile Support and Maintenance of IT Services, in: Inf. Syst. Dev., Springer New York, New York, NY, 2011: pp. 597–609.

[23] A. Haug, F. Zachariassen, D. van Liempd, The costs of poor data quality, Journal of Industrial Engineering and Management. 4 (2011).

[24] J. Tiihonen, T. Soininen, T. Männistö, R. Sulonen, State-of-the-practice in Product Configuration - A survey of 10 cases in the Finish Industry, in: T. Tomiyama, M. Mäntylä, S. Finger (Eds.), Knowledge Intensive CAD, 1st ed., Chapman & Hall, 1996: pp. 95–114.

[25] N. Chapin, Software maintenance types-a fresh view, in: Conference on Software Maintenance. ICSM-94, IEEE Comput. Soc. Press, 2000: pp. 247–252.

[26] R.L. Glass, Frequently forgotten fundamental facts about software engineering, IEEE Softw. 18

(2001) 112–111.
[27] A. Haug, L. Hvam, N.H. Mortensen, Definition and evaluation of product configurator development strategies, Computers in Industry. 63 (2012) 471–481.
[28] T. Blecker, N. Abdelkafi, B. Kaluza, G. Friedrich, Controlling variety-induced complexity in mass customisation: a key metrics-based approach, International Journal of Mass Customization. 1 (2006) 272–298.
[29] A. Felfernig, G. Friedrich, D. Jannach, M. Stumptner, Consistency-based diagnosis of configuration knowledge bases, Artificial Intelligence. 152 (2004) 213–234.
[30] S. MADNICK, R. WANG, X. XIAN, The Design and Implementation of a Corporate Householding Knowledge Processor to Improve Data Quality, Journal of Management Information Systems. 20 (2003) 41–70.
[31] A. Haug, J. Stentoft Arlbjørn, A. Pedersen, A classification model of ERP system data quality, Industrial Management and Data Systems. 109 (2009) 1053–1068.
[32] C. Batini, C. Cappiello, C. Francalanci, A. Maurino, Methodologies for Data Quality Assessment and Improvement, ACM Computing Surveys 41 (2009).
[33] A. Even, G. Shankaranarayanan, UTILITY COST PERSPECTIVES IN DATA QUALITY MANAGEMENT, Journal of Computer Information Systems. 50 (2009) 127–135.
[34] G. O'Regan, Capability Maturity Model Integration, in: Concise Guid. to Softw. Eng., Springer International Publishing, 2017: pp. 255–277.
[35] K.S. Ryu, J.S. Park, J.H. Park, A Data Quality Management Maturity Model, ETRI Journal. 28 (2006) 191–204.
[36] A. Even, G. Shankaranarayanan, Utility-driven configuration of data quality in data repositories, International. Journal of Information Quality. 1 (2007) 22.
[37] M.A.M. Capretz, M. Munro, Software configuration management issues in the maintenance of existing systems, Journal of Software Maintenance: Research and Practice. 6 (1994) 1–14.
[38] A. Haug, L. Hvam, The modeling techniques of a documentation system that supports the development and maintenance of product configuration systems, International Journal of Mass Customisation. 2 (2007).
[39] C.S. Pui Ng, G. Gable, Taizan Chan, An ERP maintenance model, 36th Annual Hawaii Int. Conference on Systems Sciences. 2003. IEEE, 2003: p. 10 pp.
[40] C.C.H. Law, C.C. Chen, B.J.P. Wu, Managing the full ERP life-cycle: Considerations of maintenance and support requirements and IT governance practice as integral elements of the formula for successful ERP adoption, Computers in Industry. 61 (n.d.) 297–308.
[41] J.L. Salmeron, C. Lopez, A multicriteria approach for risks assessment in ERP maintenance, Journal of Systems and Software. 83 (2010) 1941–1953.
[42] P. Müller, Configuration management – a core competence for successful through-life systems engineering and engineering services, Procedia CIRP. 11 (2013) 187–192.
[43] R. Marsh, Drowning in dirty data? It's time to sink or swim: A four-stage methodology for total data quality management, Journal of Database Marketing and Customer Strategy Management. 12 (2005) 105–112.
[44] W. Kim, B. Choi, Towards Quantifying Data Quality Costs., Journal of Object Technology. 2 (2003) 69. doi:10.5381/jot.2003.2.4.c6.
[45] M.J. Eppler, M. Helfert, A CLASSIFICATION AND ANALYSIS OF DATA QUALITY COSTS, in: Proceedings of the Ninth International Conference on Information Quality., 2004: pp. 311–325.
[46] I. Benbasat, D.K. Goldstein, M. Mead, The Case Research Strategy in Studies of Information Systems, MIS Quarterly. 11 (1987) 369–386.
[47] C. Voss, N. Tsikriktsis, M. Frohlich, Case research in operations management, International Journal of Operations and Production Management. 22 (2002) 195–219.
[48] J. Meredith, Building operations management theory through case and field research, Journal of Operations Management. 16 (1998) 441–454.
[49] D.M. McCutcheon, J.R. Meredith, Conducting case study research in operations management, Journal of Operation Management 11 (1993) 239–256.

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